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(54) Reduction of image artefacts in computed tomography

(57) Image reconstruction errors and artefacts can occur in computed tomography in which a body section 3 contained within a positioning zone 25 is only scanned completely throughout a smaller scanning zone 2 as a result of the incompleteness of measurement in the scanned regions 31 and 32 of the body section outside the zone 2.

According to the present invention the respective difference value is formed between the sum of all absorption values measured in a series relating to each direction and the maximum. For each direction associated with a non-zero difference value, the measurement values are complemented by *a priori* values each proportional to the length of measurement beam in the body section but outside the scanning zone 2. The boundary of the body section is determined from tangential measurement beams inside the zone 2 and by interpolation therefrom outside that zone. A central vector is defined for a predetermined set of directions, and the boundary is identified as the first radial intercept along the vector direction with a tangential beam path.

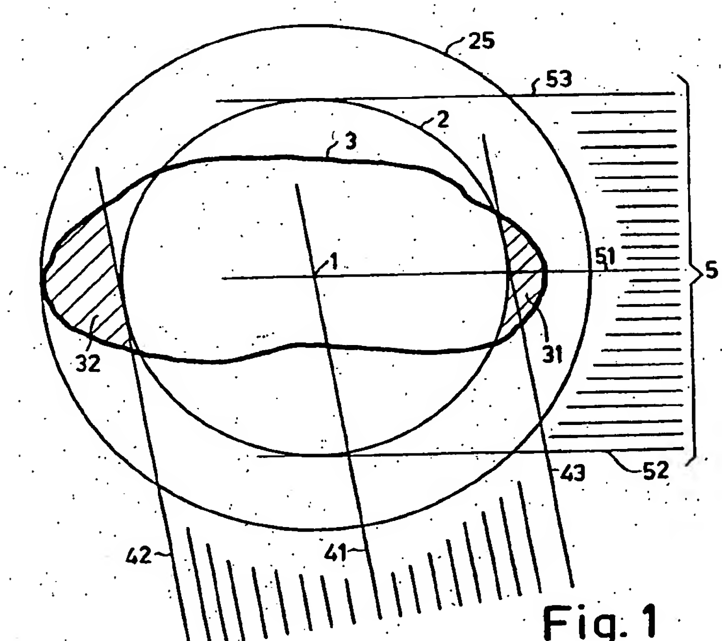

Fig. 1

GB 2 009 560 A

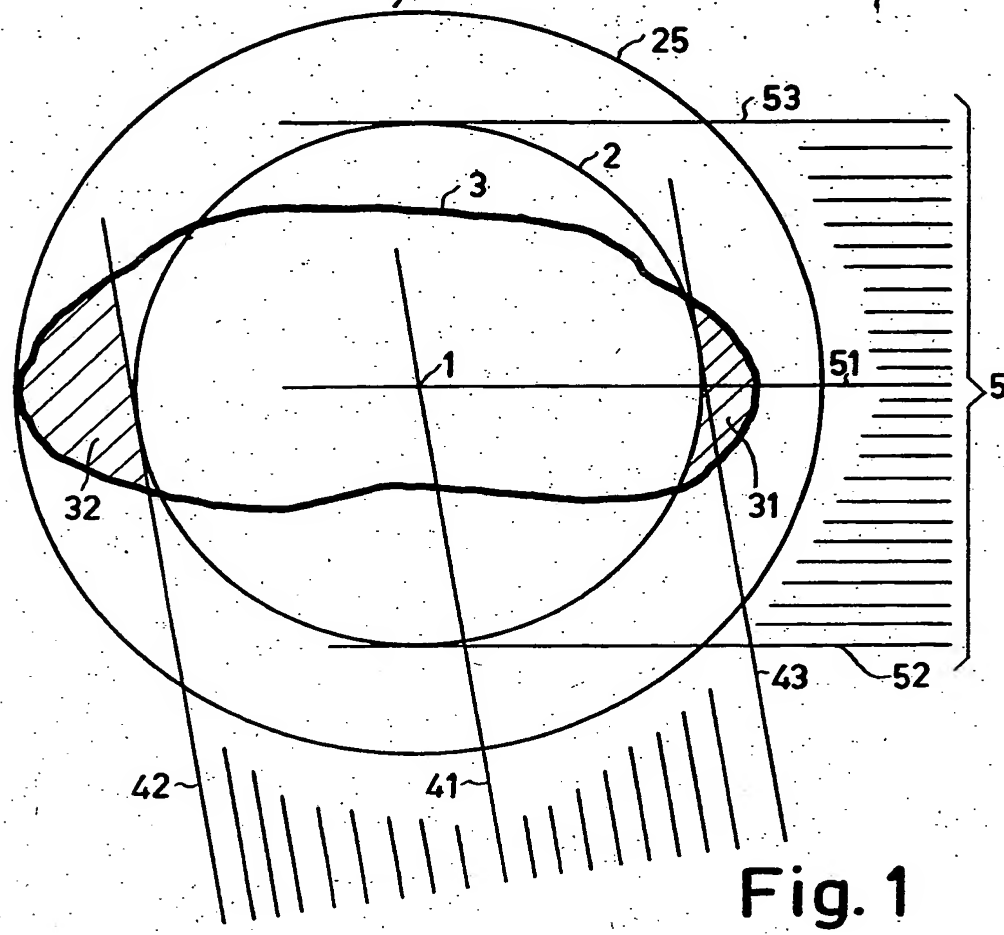
25
53
2
3
1
51
5
32
31
43
52
42
41

Fig. 1

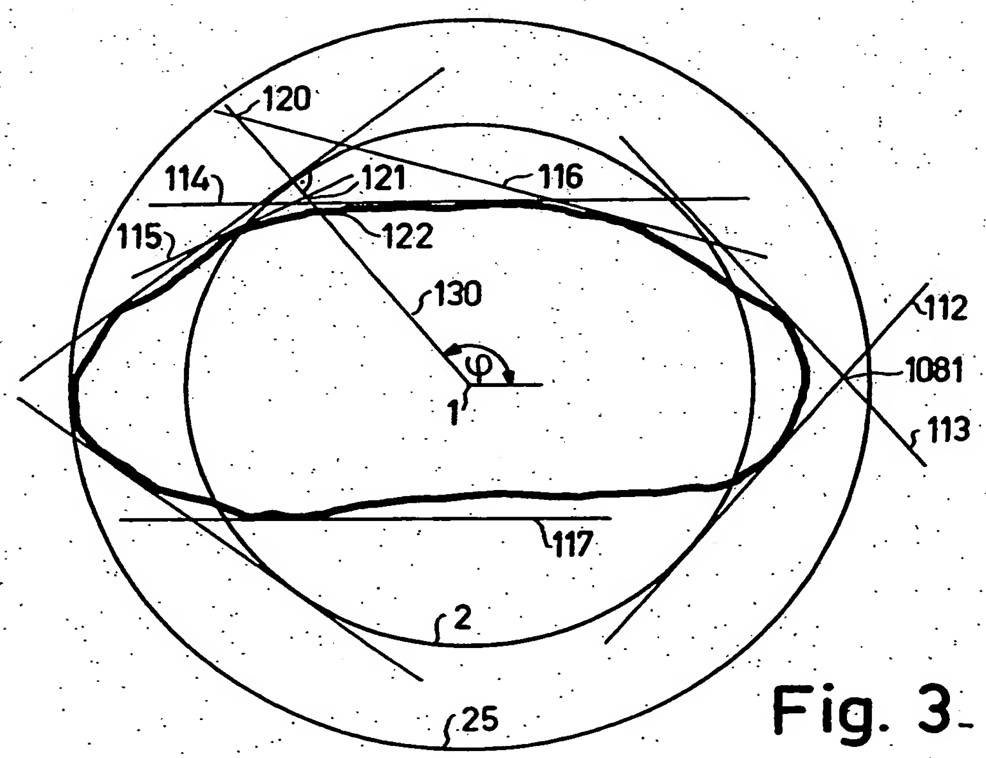
120
114
121
116
115
122
130
112
φ
1081
1
113
117
2
25

Fig. 3

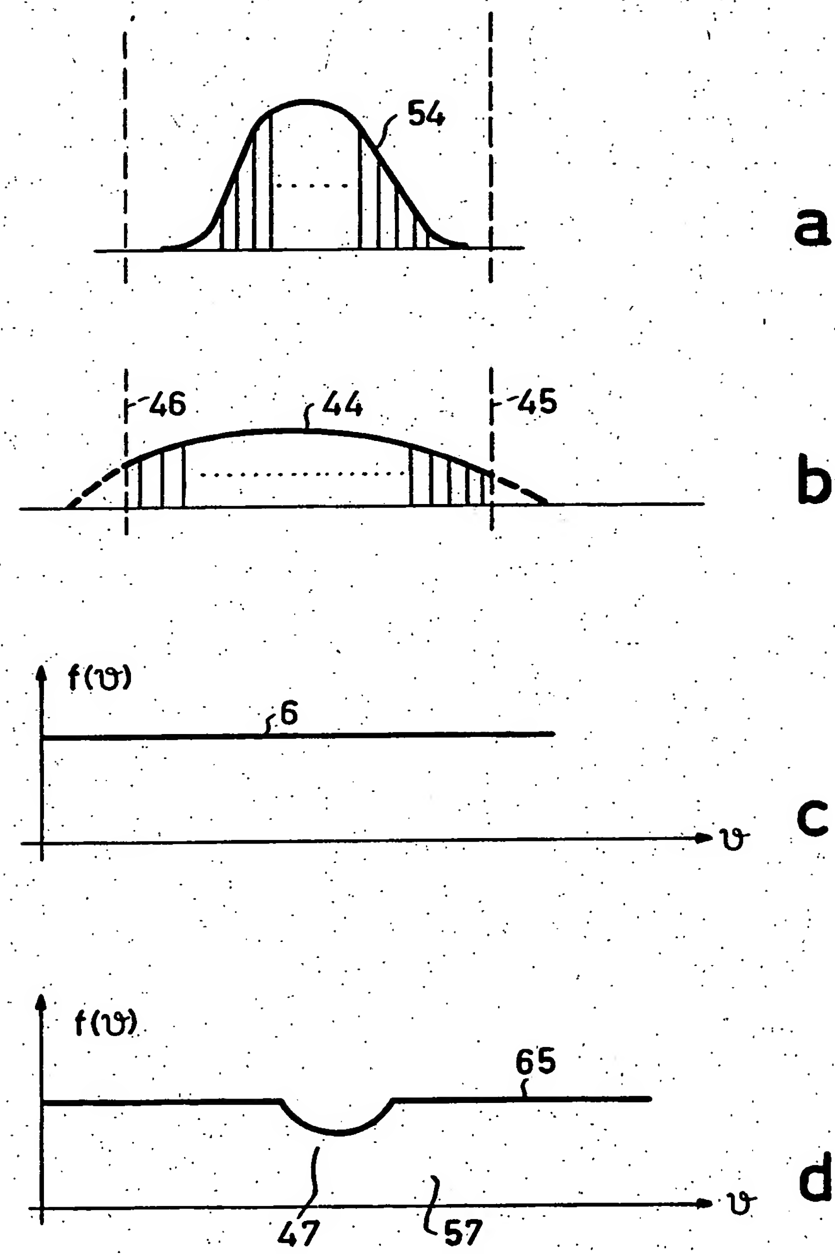

Fig. 2

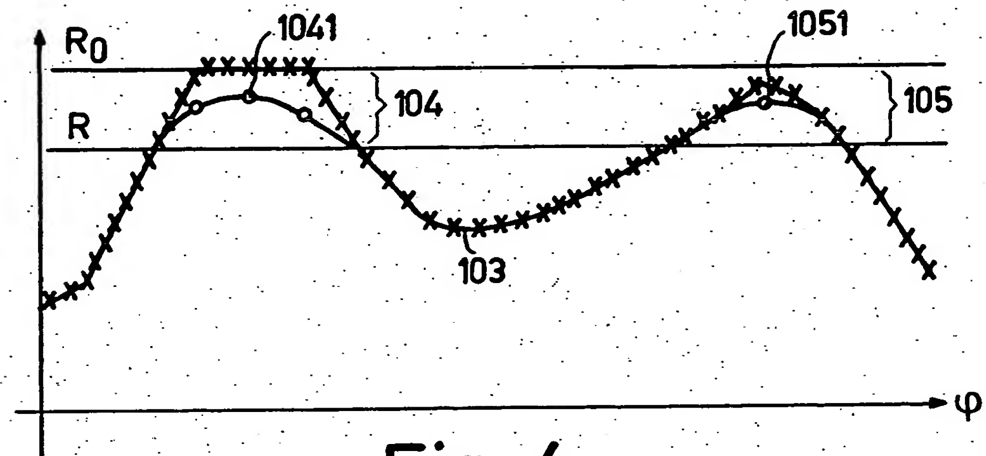
R0
R
1041
104
1051
105
103
φ

Fig. 4

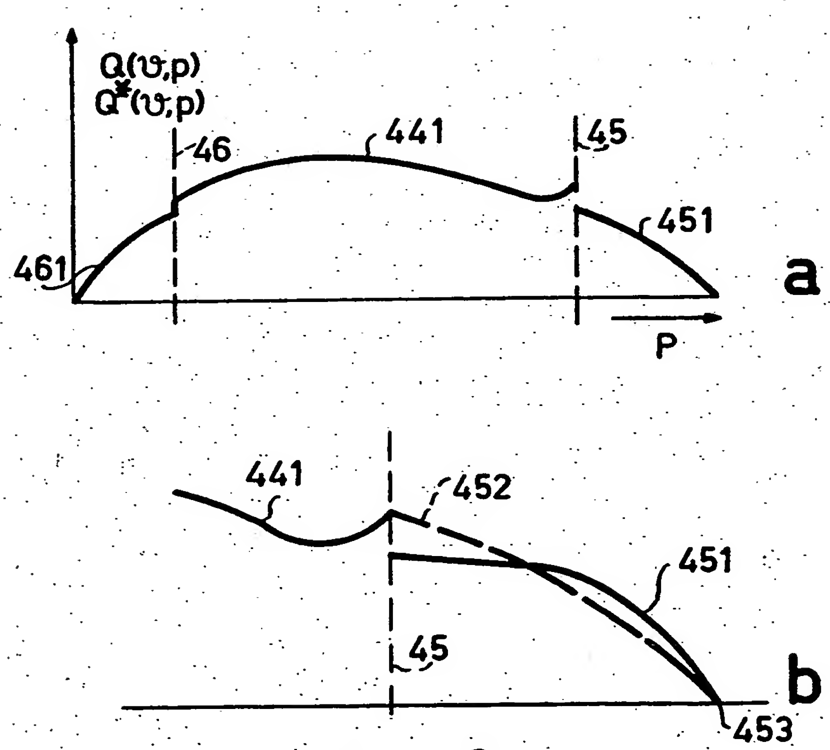
Q(ϑ,p)
Q*(ϑ,p)
46
441
45
451
461
a
P
441
452
451
45
b
453

Fig. 6

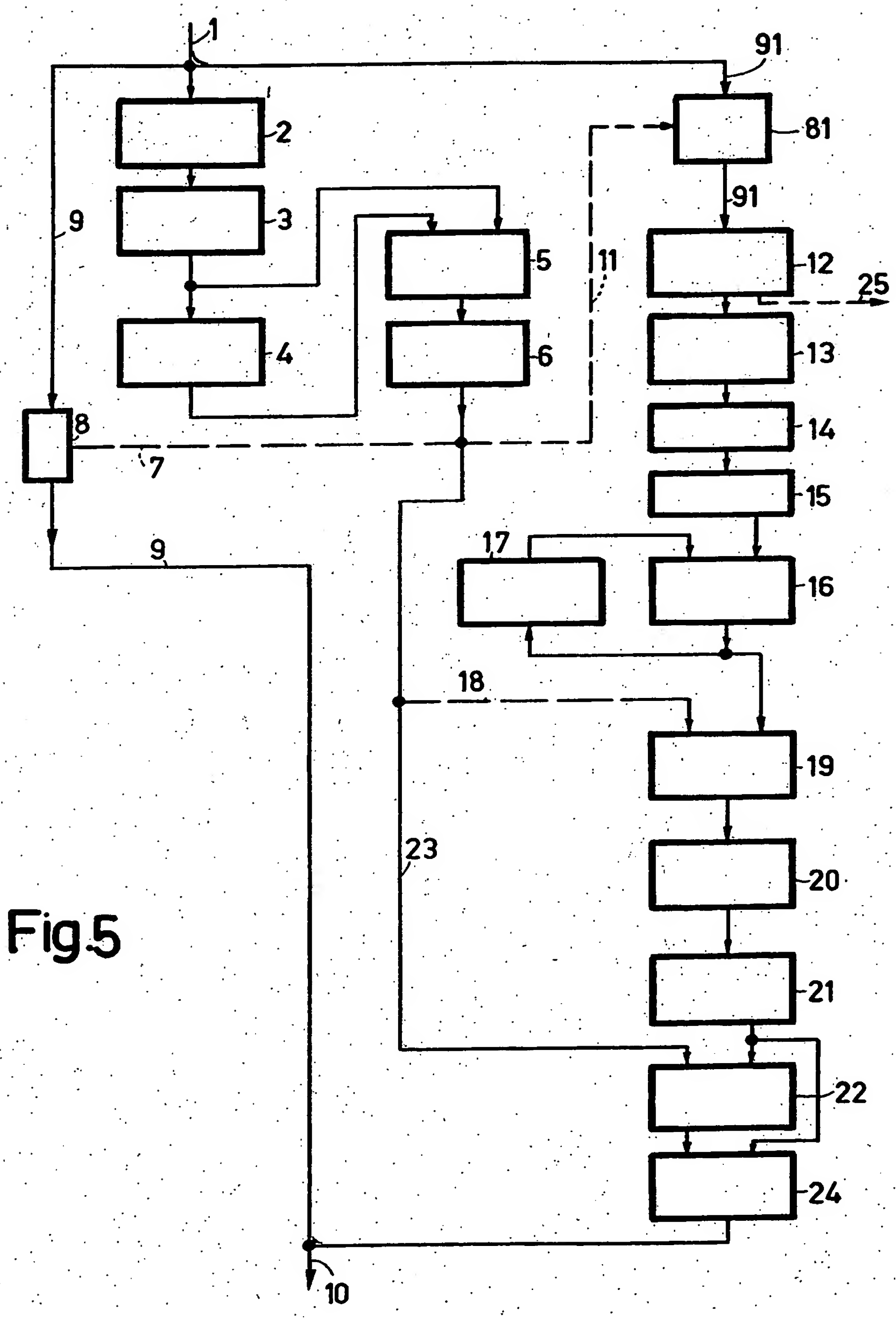

Fig.5

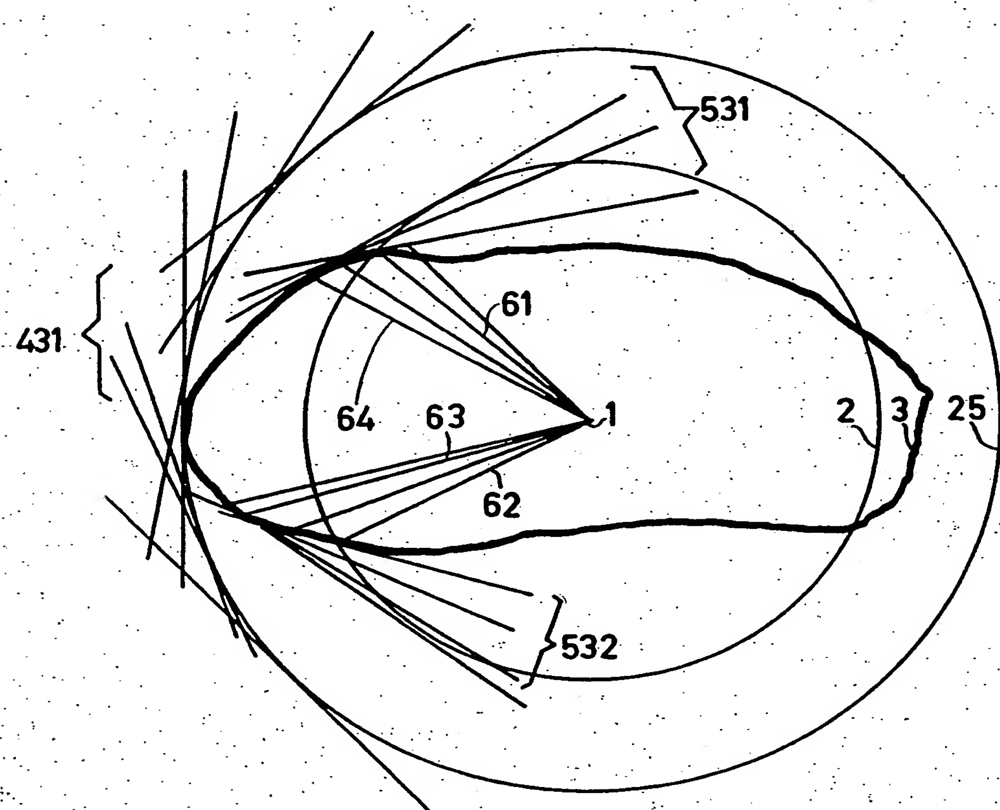

Fig.7

SPECIFICATION

Method of determining the spatial distribution of radiation absorportion in a body section

The invention relates to a method of determining the spatial distribution of radiation absorportion in a planar section of a body from a plurality of measurement series, each of which represents a sequence of measurement values, each said value corresponding to the integral of the absorportion of the body along a respective one of a plurality of parallel measurement beam paths which pass through a scanning zone, the various measurement series being formed from measurement values relating to measurement beam paths, oriented in corresponding different directions, the planar section of the body to be examined being completely scanned by corresponding measurement beams when directed in at least one of the directions.

A method of this kind has been proposed hitherto, for example, from U.K. Patent Specification Number 1,283,915. Therein, the absorption distribution is reconstructed from the measurement values by means of a computer utilizing suitable algorithms.

Therein, the scanning zone is a zone which is irradiated throughout and in succession from different directions. In the arrangements proposed hitherto for performing the method, the body whose absorption distribution is to be determined in one planar section thereof must be positioned inside the, normally circular, scanning zone. This means that there may be no part of the body section which is not irradiated by the radiation in any of the measurement directions. Otherwise, as tests have shown, serious errors will tend to occur during the computed reconstruction of the local absorption distribution, even within the scanning zone which is itself completely scanned by the measurement beams. These errors may be caused by inaccurate positioning of the body to be examined inside a positioning zone when this zone is itself larger than the scanning zone, or by the fact that the body section has an elliptical boundary whose major axis is longer than the diameter of the scanned zone.

Therefore, the present invention has for an object to provide an improved method of the kind referred to in which errors caused by the fact that parts of the body section under examination are not irradiated by the radiation in at least one direction can be reduced.

According to the invention there is provided a method of determining the spatial distribution of absorportion ($\mu(x,y)$ of radiation in a planar section of a body from plurality of measurement series, each of which represents a sequence of measurement values (Q, ν, p) each said value corresponding to the integral of the absorption of the body along a respective one of a plurality of parallel measurement beam paths which pass through a scanning zone in a direction ν, each measurement beam path being a distance p from the central beam path of the series, the various measurement series being formed from measurement values relating to measurement beam paths oriented in corresponding different directions, the section of the body to be examined being completely scanned by corresponding measurement beams when directed in at least one of the directions, characterized in that the sum of ($f(\nu)$ of all measurement values ($Q(\nu, p)$) of a measurement series is formed and that the difference ($K(\nu)$) between each sum and the maximum (A) of all sums is determined, and in the case in which at least one of the differences ($K(\nu)$) thus formed departs from zero, *a priori* values ($Q^x(\nu, p)$) are formed to complement the measurement values, such that for each beam direction ν the sum of the *a priori* values ($Q^x(\nu, p)$) corresponds to the difference ($K(\nu)$) determined for the measurement series corresponding to that direction, each *a priori* value ($Q^x(\nu, p)$) for each direction being proportional to that length ($L(\nu, p)$) of a corresponding beam path which extends through the body section in that region which is outside the scanning zone and in said direction, said length corresponding to the distance between the two points of intersection ($\overline{x}_1, y_1$; x_2, y_2) of said beam path with the boundary of the body section, said boundary being determined as the envelope of all beam paths which are tangential to the boundary of the body section inside the scanning zone, or as an extension of said envelope which is determined by interpolation, the reconstruction of the absorption distribution ($\mu(x,y)$) inside the scanning zone being computed from the measurement values ($Q(\nu, p)$) and the *a priori* values ($Q^x(\nu, p)$).

Thus, *a priori* values are formed by the method embodying the invention, *i.e.* values which do not follow directly from a measurement and which at least approximately represent the absorprtion of the body outside the scanning zone, the reconstruction of the absorption distribution inside (and in given cases also outside) the scanning zone is realized on the basis of the measurement values and the *a priori* values. The idea of replacement of missing measurement values has been proposed (B.E. Oppenheim, "Image processing for 2-D and 3-D reconstruction from projections", Stanford University, U.S.A., 1975) but no suitable method of determining the *a priori* values has been described.

The invention is based on the recognition of the following:

a) The integral overall measurement or the sum of all the measurement values in one direction, in other words, the sum of all measurement values of a measuring series, forms a value which is substantially constant and independent of the direction of the beams in the case of *complete* scanning. "substantially constant and independent" is to be understood to mean herein that uncertainties of measurement caused by the physical nature of the measurement give rise to a small fluctuation of the integral value. This fluctuation, which may be the reason why the integral over all measurement values is not exactly constant when the body section is completely scanned, should be considered negligibly small hereinafter.

This assumption is based on the fact that the area integral of the absorption in the body section examined is independent of the direction of the pair of rectangular coordinates lying in the body section and along which the area integral of the absorption is formed. Because each measurement value represents the line integral of the absorption in a given direction, the integral over all measurement values along adjacent paths each in a given direction i.e. the integral in the direction perpendicular to said given direction is equal to the area integral of the absorption. Therefore, the sum of all measurement values in one direction, namely of one measurement series, will be a constant and independent of that direction.

In the case of a *partly incomplete* scan (during which the body section is completely scanned by the radiation in at least one direction in the section under examination and incompletely scanned in at least one other direction), a maximum value will be formed for the integral of the set of measurement values relating to a direction for which the body slice has been completely scanned. In other directions, smaller integral values must result. The difference between this maximum value and the integral value relating to given direction will thus correspond to the integral value or the sum of the *a priori* values required for that direction.

b) Examinations using arrangements of the described kind have shown that the X-ray absorption by biological tissue varies within only narrow limits in major regions of the human body. Therefore, it may be assumed that the absorption inside the body is constant for a given direction along all beams situated outside the scanning zone.

c) The outer boundary of a section of a human torso or head may be represented as a closed and smooth curve. For regions of the body which are situated inside or at the edge of the scanning zone, the position of the outer boundary can be derived directly from the measurement values as an envelope formed from all measurement beam paths which are tangential to the boundary of the body section. For those parts of the body section which remain outside the scanning zone, the position of the boundary curve can be approximated by interpolation. The length of the beam paths passing through the body section which are assumed to be situated outside the scanning zone is thus approximately defined. The *a priori* values can be calculated on the basis thereof.

An embodiment of the invention will now be described by way of example, with reference to the accompanying drawings, of which:–

Figure 1 shows the geometrical arrangement of a section of a body to be examined with respect to the scanning zone and the positioning zone,

Figures 2a and b illustrate the variation of the measurement values of a measurement series,

Figures 2c and d respectively show the sum value of the measurement series as a function of the irradiation direction for a completely scanned body section and for a partly incompletely scanned body section,

Figure 3 is a diagram which shows an example of the determination of a central vector,

Figure 4 shows the variation of the central vectors as a function of the polar angle φ,

Figure 5 shows diagrammatically an arrangement for performing a method embodying the invention,

Figure 6 illustrates the variation in the measurement values and in the *a priori* values, and

Figure 7 is a diagram which further illustrates the geometrical arrangement of an incompletely scanned body section.

Figure 1 illustrates a circular scanning zone 2, having a centre 1, which is generally also the centre of rotation of an assembly formed by a radiator and a detector array. The radiator, the detector array, the motors and the drives and all other mechanical parts are not shown since they may be of similar construction to that employed in apparatus for computed tomography hitherto proposed (for example, as in the apparatus described in U.K. Patent Specification No. 1,283,915). Regions 31 and 32 of a body section 3 to be examined, are situated outside the scanning zone 2, but inside a positioning zone 25 which is assumed to be circular and concentric with the scanning zone 2. The outer boundary of the body shown in Fig. 1 corresponds to a section through the upper thorax and the shoulder bones. The measurement beam paths 4 and 5 (which are the beams or strip paths along each of which the absorption is determined and represented by a measurement value during a measurement), belonging to two different series, are shown by way of example, said beams irradiating the scanning zone 2 along different angular directions but always scanning the whole of the scanning zone 2. The central beams passing through the centre 1 of the scanning zone 2 are denoted by the references 41 and 51, while the other measurement beams which are tangential to the scanning zone 2 are denoted by the references 42, 43 and 52, 53, respectively. It can be seen that the measurement series denoted by the reference 5 completely covers the body 3 and that the measurement series 4 does not completely cover the body 3, the shaded areas 31 and 32 not being covered.

The Figures 2a and 2b are graphs 54 and 44, respectively, of th measurement values $Q(\nu, p)$ measured in the measurement series 5 and 4. $Q(\nu, p)$ serves to express that each measurement value is a function of the direction measured from the vertical in the figures, in which the measurement beam irradiates the body during the determination of the measurement value, this direction being the same for all measurement values of a measurement series, and also a function of the position p of a measurement beam path with respect to a straight line extending perpendicularly to the measurement beam path direction, and is the distance between the relevant measurement beam and a corresponding beam through the scan centre, the said distance p relating to measurement beam paths which are situated to one and to the other

side of the central beam path, having opposite signs. It will be apparent from Figures 2a and 2b that the curve 54 varies relatively gradually, while the curve 44 goes abruptly to the value zero at the edges 45 and 46 where it represents the measurement values along the outer measurement beam paths 42 and 43. Each of the measurement values represented by one of the curves 44 and 45 can be calculated in known manner by means of the formula:

$$Q(\vartheta, p) = \int_{-\infty}^{\infty} \mu(x,y)\,ds \qquad (1)$$

in which $Q(\nu,p)$ is the measurement value determined along the measurement beam path having a direction ν and a distance p from the scan centre, and $\mu(x,y)$ is the absorption of the body slice at the point (x,y) of a fixed rectangular system of coordinates. The quantity s is a coordinate extending along the direction of the measurement beam path.

When the integral $f(\nu)$ over all measurement values of a measurement series is formed, the following is obtained:

$$f(\vartheta) = \int_{-\infty}^{\infty} Q(\vartheta, p)\,dp = \iint_{-\infty}^{+\infty} \mu(x,y)\,dp\,ds \qquad (2)$$

in which p and s form a coordinate system rotated in synchronism with ν and having a fixed coordinate origin at the scan centre 1. Because this integral $f(\nu)$ corresponds to the area integral of the absorption of the body over the plane of examination, which is independent of the direction ν, as has already been stated, this independence must also be applicable to $f(\nu)$, so that for a complete scan of the body section the graph 6 of the function $f(\nu)$ in dependence on ν results, *i.e.* $f(\nu)$ is independent of ν and is of a constant value = A. This relation is applicable whenever the measurement value $Q(\nu, p)$ is proportional to the line integral of the absorption in the direction ν along the measurement beam path having the positional distance p. This property, assumed to be a given factor hereinafter, can be obtained in known manner, for example, by forming the logarithm of the intensity ratio of the unattenuated measurement beam to the measurement beam attenuated by the body. Furthermore, the integral $f(\nu)$ is not formed by a real integration in practice, but rather by summing all the measurement values in a measurement series. However, this does not affect the validity of the considerations underlying the present embodiment.

For a measurement series which does not completely cover the body section 3, the value of $f(\nu)$ must be less than this constant value:

$$f(\vartheta) = \int_{-R}^{+R} Q(\vartheta, p)\,dp < A \qquad (3)$$

Therein, R is the radius of the scanning zone and A is the previously mentioned constant value. During an examination involving a partly incomplete scan of the body section (i.e. during an examination in which the body is completely scanned during some of the measurement series, whilst it is not completely scanned during other said series), the constant value A can be obtained as a maximum of the various values $f(\nu)$:

$$A = \mathrm{Max}_{\vartheta} \{f(\vartheta)\} \qquad (3a)$$

Fig. 2d shows, by way of example, a graph 65 of the integral value $f(\nu)$ for the case (shown in Fig. 1) concerning a partly incomplete scan, the references 47 and 57 denoting the direction of the measurement beams of the measurement series 4 and 5, respectively.

The equations (3) and (3a) are used in the embodiment of the invention to establish whether the case of a partly incomplete scan has occurred and for calculating the integral value $K(\nu)$ of *a priori* values $Q^x(\nu, P)$ necessary to complement the measurement values. This is because:

$$K(\vartheta) = \int_{-\infty}^{-R} Q^x(\vartheta, p)\,dp + \int_{R}^{+\infty} Q^x(\vartheta, p)\,dp = A - f(\vartheta) \qquad (4)$$

If K (ν) is greater than zero, this is proof of an incomplete scan only if no errors have occurred in the various measurement series. On the other hand, in the case where it has been ascertained that the body has been completely scanned, an error (caused, for example, by movements of the body or fluctuations of the detector sensitivity) may be assumed when K (ν) is greater than zero.

When it can be assumed, as has already been mentioned, that the absorption at or adjacent the boundary of the body section, for the most part departs only slightly from a mean value, the equation (4) can be used for determining the *a priori* values in the regions 31 and 32 (Fig. 1) outside the scanning zone 2, provided hat the area of the body section outside the zone is known. In that case, the following must be applicable for each *a priori* value $Q^x(\nu, p)$:

$$Q^x(\vartheta, p) = C(\vartheta) \cdot L(\vartheta, p) \qquad (6)$$

wherein $C(\nu)$ is a proportionality factor and $L(\nu, p)$ is the length, yet to be determined, of an (assumed) beam path which irradiates the body in that region lying outside the scanning zone but inside the body. The following is then obtained in combination with the equation (4(;

$$K(\vartheta) = C(\vartheta) \cdot \left[\int_{-\infty}^{-R} L(\vartheta, p)\,dp + \int_{R}^{\infty} L(\vartheta, p)\,dp \right] \qquad (7)$$

Therefore, when the lengths $L(\nu, p)$ have been determined, which will be described hereinafter, the factors C (ν), being constant for a given direction ν, and hence the *a priori* values $Q^x(\nu, p)$, can be calculated by means of the relations (4), (6) and (7). For the determination of $L(\nu, p)$, the embodiment utilizes the fact that the body section generally has a closed, smooth and substantially convex boundary. This boundary can be described by a series of central vectors r (φ), where:

$$|r(\varphi)| = \sqrt{x^2(\varphi) + y^2(\varphi)} \qquad (8)$$

where $x(\varphi)$, $y(\varphi)$ is the point of intersection of a central vector, originating from the centre 1 of the scanning zone 2 in the direction φ, with the boundary of the body section. When the vector lengths $|r(\varphi)|$ are plotted as a function of φ, a substantially gradual curve is obtained.

For determining the boundary of the body section, firstly those beam paths p_3 and p_4 (see the beams 114 ... 117 in Fig. 3) must be determined which are tangential to the boundary of the body section under examination. For these 'measurement beam paths, the following is applicable in the interval between p_3 and p_4:

$Q(\vartheta, p) > 0$ or

$Q(\vartheta, p) = 0$ outside the interval $[p_3, p_4]$ (9)

Fig. 3 shows the points of intersection of a radial line 130, extending in the direction φ, with tangential beam paths 114, 115 and 116 thus established, said points being denoted by the references 120, 121 and 122. It can be seen that the point of intersection 122, being situated at the smallest distance along the radial line 130 from the centre 1, substantially coincides with the edge of the body. This relation can be generalized:

$$|r(\varphi)| = \mathrm{Min}_{\vartheta} \left\{ \sqrt{x^2(\varphi, \vartheta) + y^2(\varphi, \vartheta)} \right\} \qquad (10)$$

in which $x(\varphi, \vartheta)$ and $y(\varphi, \vartheta)$ is the point of intersection of the radial line extending in the direction φ and a beam which extends in the direction ϑ and is tangential the boundary of the body section; for $x(\varphi, \vartheta)$ and $y(\varphi, \vartheta)$:

$$\begin{aligned} x(\varphi, \vartheta) &= p_{3/4}(\vartheta) \cdot 1/(\sin\vartheta \cdot \tan\varphi + \cos\vartheta) \\ y(\varphi, \vartheta) &= p_{3/4}(\vartheta) \cdot 1/(\sin\vartheta + \cos\vartheta \cdot \tan\varphi) \end{aligned} \qquad (11)$$

wherein the angle in this expression is the angle between a straight line which extends horizontally to the right (in Fig. 3) from the centre 1 and the perpendicular from the centre to the tangentially extending measurement beam path.

In order to prevent successive errors during the determination of the vectors $r(\varphi)$ in the case of a beam path direction for which the positioned distance of $p_3 = R$ and/or of $p_4 = -R$, and $K(\vartheta) > 0$, the relation (9)

must be completed by

$p_3 = +R_0$

or (9a)

$p_4 = -R_0$

where R_0 is the radius of the positioning zone 25 (see Fig. 1) and the sign of R_0 depends on whether the position of p_3 or p_4 is to one side or to the other with respect to the central beam. For the configuration shown in Fig. 3, the variation of the central vectors $r(\varphi)$ as a function of φ as shown in Fig. 4 in thus obtained. The reference of 104 denotes that portion of vectors $r(\varphi)$ which correspond to the boundary region of the body section lying outside the scanning zone 2 to the left in Fig. 3. In accordance with the equations (9a), (10) and (11), the maximum vector length is limited to approximately R_0. The reference 105 denotes that portion of the vectors $r(\varphi)$ which correspond to the boundary region of the body section lying outside the scanning zone 2 to the right in Fig. 3. Because the point of intersection 1081 (Fig. 3) is in this case situated inside the boundary 25 of the positioning zone in the device, the vector lengths are not limited. The references 1041 and 1051 in Fig. 4 represent the variation of the true vector lengths $|r(\varphi)|$ in accordance with the relation (8).

In order to reduce the difference between the two curves, and hence the errors in the determination of $r(\varphi)$, the vector length determined in accordance with the equation (10) is replaced by a corrected value $r^x(\varphi)$, where:

$$r^x(\varphi) = r(\varphi_1) \cdot a_1 + r(\varphi_{-1})a_2 + r(\varphi_2) \cdot a_3 + r(\varphi_{-2})\, a_4 + \ldots \quad (10a)$$

The interpolation in accordance with the equation (10a) is performed whenever $|r(\varphi)|$, determined in accordance with the equation (10), has a value which is greater than the radius R of the scanning zone. In this respect, use is made of values $r(\varphi_1) \ldots r(\varphi_2)$ which are smaller than or at the most equal to R, their angular positions $\varphi_1 \ldots \varphi_2$ being nearest to the position φ. The terms $a_1, a_2, a_3, a_4 \ldots$ are interpolation coefficients which are fixed in accordance with known interpolation methods, and the angles φ satisfy the relationship: $\varphi_{-2} < \varphi_{-1} < \varphi_1 < \varphi_2$. The boundary of the body 3 is thus approximately determined by the vectors $r(\varphi)$ or $r^x(\varphi)$.

Using $r(\varphi)$ and $r^x(\varphi)$, each one of a set of lengths $L(\vartheta, p)$ can be calculated as the distance between two corresponding points of intersection (x_1, y_1) and (x_2, y_2) of a beam path which extends outside the scanning zone 2 in a direction ϑ and having the positional distance $p > R$, with the boundary of the body section 3. In this respect:

$$L(\vartheta, p) = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

where $x_1 = |r(\varphi')| \cdot \cos\varphi'$, $x_2 = |r(\varphi'')| \cdot \cos\varphi''$

$y_1 = |r(\varphi')| \cdot \sin\varphi'$, $y_2 = |r(\varphi'')| \cdot \sin\varphi''$ (12)

The polar angles φ' and φ'' of the two central vectors, terminating in the said points of intersection, are determined in accordance with the following condition:

$$\left| p/\cos(\vartheta - \varphi') - |r(\varphi')| \right| < \varepsilon$$

or (13)

$$\left| p/\cos(\vartheta - \varphi'') - |r(\varphi'')| \right| < \varepsilon$$

Therein, ε is a small value in comparison with the radius R of the scanning zone, for example, $\varepsilon = R/100$. The angle φ is then varied until the relation (13) is satisfied.

Hereinafter, the calculation process will be described for performing a method embodying the invention by means of a computer which is diagrammatically shown in Fig. 5. The measurement values $Q(\vartheta, p)$ arrive from a memory (not shown), *via* a data line 1, in an arithmetic unit 2 in which the integral or the sum of all measurement values $f(\vartheta)$ is formed in accordance with the equation (3) for each measurement series, *i.e.* for each ϑ. The values $f(\vartheta)$ thus calculated are stored in a memory 3. An arithmetic unit 4 determines, in accordance with the equation (3a), the maximum value A of the values stored in the memory 3. An arithmetic unit 5 determines, on the basis of the values $f(\vartheta)$ stored in the memory 3 and the maximumm value A calculated in the arithmetic unit 4, the differences $K(\vartheta)$ in accordance with the equation (4) and stores these values in a memory 6. From the memory 6 a control logic line 7 extends to a switch 8 which enables a signal path 9 for the measurement values $Q(\vartheta, p)$ when all the differences $K(\vartheta)$ are zero or less than a predetermined low threshold value. The measurement values $Q(\vartheta, p)$ can then be applied, without further modification, *via* a data line 10, to a known arithmetic circuit (not shown) for determining the absorption. At the same time, all further calculations in arithmetic units 12 to 24 are inhibited *via* a control logic line 11.

However, in the case of a partly incomplete scan, so that at least one value $K(\vartheta) > 0$ exists, the switch 81 is closed *via* the control logic line 11, so that the measurement values $Q(\vartheta, p)$ can be applied to the arithmetic unit 12 *via* a data line 91. This unit then determines, for all directions ϑ, the positions of the (measurement) beams which are tangential to the body by means of the equations (9) and (9a) and stores this data in a memory 13. The points of intersection $x(\varphi, \vartheta)$, $y(\varphi, \vartheta)$ for all beam directions ϑ and, preferably, 360 equidistant directions φ of the central vector, are determined in an arithmetic unit 14 in accordance with the relation (11). An arithmetic unit 15 then determines, by means of the relation (10), the vector

lengths $|r(\varphi)|$ and stores this data in a memory 16. The interpolation in accordance with the relation (10a) is performed in an arithmetic unit 17. If the value $K(\vartheta)$ becomes greater than zero for a given beam direction ϑ (which implies that the body was not completely scanned in the direction ϑ), the completion of the calculation process in an arithmetic unit 19 is enabled *via* the control logic line 18, the unit 19 calculating, using the equation (13), for all beam positions $R \geq |p| \geq R_0$, the central vectors $r(\varphi')$ and $r(\varphi'')$ whose end points (x_1, y_1) and (x_2, y_2), respectively, are situated on the beam path relating to the position *p*. If such end points exist, *i.e.* if the beam path relating to the position *p* intersects the boundary of the body section, the associated length $L(\vartheta, p)$ is calculated in an arithmetic unit 20 in accordance with the equation (12).

For beams which are situated outside the scanning zone 2 and (Fig. 1) and outside the boundary of the body section, and also for all beam directions ϑ for which the calculation is not enabled in the arithmetic unit 19 (because the body is completely scanned in the direction ϑ, so that $K(\vartheta) = 0$), the arithmetic unit 20 produces $L(\vartheta, p) = 0$. All values $L(\vartheta, p)$ are stored in a memory 21. The values $K(\vartheta)$ made available *via* the data line 23 are used in an arithmetic unit 22, in conjunction with the values $L(\vartheta, p)$ stored in the memory 21, for determining the factor $C(\vartheta)$ in accordance with the relation (7). On the basis thereof, the arithmetic unit 24 determines the *a priori* values $Q^{x}(\vartheta, p)$ to be complemented and applies these values via 10 to the arithmetic unit (not shown) for determining the absorption distribution.

Finally, it is to be noted that in the case of incomplete scanning in all beam directions μ, *i.e.* in the case where a measurement value departing from zero is determined for all beam directions at least one portion of the boundary of the scanning zone ($Q(\vartheta\ R)$, or $Q(\vartheta, -R) > 0$), the arithmetic unit 12 provides an indication, *via* a control logic line 25, on a data display (not shown) that a satisfactory determination of the absorption is not possible in these circumstances. The arrangement shown in Fig. 5 can be realized by means of known digital computer components.

The method embodying the invention can be further refined. For example, Fig. 6a shows a measurement value profile complemented by *a priori* values $Q^{x}(\vartheta, p)$ 451 and 461. As is clearly shown, at the boundaries 45 and 46 between the curve 441 which represents the measurement values $Q(\vartheta, p)$ and the curves 451 or 461 which represent the *a priori* values $Q^{x}(\vartheta, p)$ an irregularity is present which may be caused, for example, because the circular scanning zone 2 has intersected a part of the body having a higher absorption. In order to diminish such irregularities and to endeavour to ensure that a curve of the form indicated by 452 (Fig. 6b) is provided, the values $Q^{x}(\vartheta, p)$ are corrected by interpolation in an improved arrangement to provide a modified *a priori* value given by:–

$$Q^{xx}(\vartheta, p) = \Delta Q(\vartheta\ R) \cdot b_p + Q^{x}(\vartheta, p) \cdot C_2(\vartheta) \quad (14)$$

where b_p is a weighting factor for which:

$b_p = 1$ for $p = R$ and $b_p = 0$ for $p > R$ and for $Q^{x}(\vartheta, p) = 0$.

The factor $C_2(\vartheta)$ is chosen so that the area integral under the curve 451, representing the values $Q^{x}(\vartheta, p)$, is equal to the area integral under the curve 452 which represents the corrected value $Q^{xx}(\vartheta, p)$. As a result, it can be arranged that the integral over all values associated with a given beam direction ϑ is constant (= the maximum value A). The value

$$\Delta Q(\vartheta, R) = Q(\vartheta, R) - Q^{x}(\vartheta, R) \cdot C_2(\vartheta) \quad (15)$$

is defined as the difference between the measurement value $Q(\vartheta, R)$ at the edge of the scanning zone 2 and the modified *a priori* value $Q^{x}(\vartheta, R)$ along the measurement beam path for which $p = R$ and is added, weighted by b_p, to the *a priori* values in order to ensure a smooth transition at the point where $p = R$ (45 in Fig. 6).

A further improvement can be achieved when the vectors $r(\varphi)$ determined in accordance with the equation (10) are taken into account, by contrast with the conditions described with reference to the equation (10a), also for calculating the edge of the body in accordance with the equations (12) and (13) when $|r(\varphi)| > R$, subject to conditions which will be explained hereinafter. As a result, the number of vectors which are to be replaced by interpolated values $r'(\varphi)$ is reduced, so that the edge of the body can be more accurately determined.

For an explanation of the required conditions, the beam positions calculated in accordance with relation (9) are shown in Fig. 7 for various beam directions ϑ. Therein, 531 and 532 denote groups of beams which extend through the scanning zone 2, and the reference 431 denotes a group of beams which extends outside the scanning zone 2 and for which *p* is made equal to $\pm R_0$ in accordance with the equation (9a), the length of the vectors 61 and 62 corresponding exactly to the radius R of the scanning zone 2. It can be seen that there are also vectors whose length exceeds the radius of the scanning zone 2, for example, the vectors 63 and 64 which correctly describe the boundary of the body section. However, not all vectors between the vectors 63 and 64 are suitable for describing the boundary of the body section 3, so that they must be replaced by interpolation in accordance with the equation (10a). In order to determine in which the angular region of ϑ the central vectors must be replaced by interpolation, use can be made of the fact that a gradually monotonously decreasing or increasing relationship exists between the angle φ of the central vector and the angle ϑ of the measurement beam path on which the central vector terminates for a body section whose boundary is convex in the plane of examination. Therefore, when the determined central vector equals the radius R_0 of the positioning zone 25, or when the central vector terminates each time on the same measurement beam path ($p = R$) extending from the outer edge of the scanning zone 2, the value of $R(\varphi)$ must be determined by interpolation in accordance with the equation (10a).

The method embodying the invention can also be used for scanning systems in which a group of

diverging beams simultaneously completely scans the body section, because groups of beams of this kind can be re-arranged to form groups of parallel beams by known methods. Scanning systems of this kind are sometimes referred to as third-generation scanners; the scanning zone is then completely irradiated by a fan-shaped radiation beam which originates from the radiator. Similarly, the method embodying the invention can also be used for so-called second-generation scanners. It is also to be noted that the method embodying the invention of X-radiation, but also for the determination of the distribution of the emission of gamma-radiation utilizing a so-called radionuclide scanner.

CLAIMS

1. A method of determining the spatial distribution of absorption ($\mu(x, y)$) of radiation in a planar section of a body from a plurality of measurement series, each of which represents a sequence of measurement values ($Q(\nu, p)$) each said value corresponding to the integral of the absorption of ths body along a respective one of a plurality of parallel measurement beam paths which pass through a scanning zone in a direction ν, each measurement beam path being a distance p from the central beam path of the series, the various measurement series being formed from measurement values relating to measurement beam paths oriented in corresponding different directions, the section of the body to be examined being completely scanned by corresponding measurement beams when directed in at least one of the directions, characterized in that the sum ($f\nu$)) of all measurement values ($Q(\nu, p)$) of a measurement series is formed and that the difference ($K(\nu)$) between each sum and the maximum (A) of all sums is determined, and in the case in which at least one of the differences ($K(\nu)$) thus formed departs from zero, *a priori* values ($Q^x(\nu,p)$) are formed to complement the measurement values, such that for each beam direction ν the sum of the *a priori* values ($Q^x(\nu, p)$) corresponds to the difference ($K(\nu)$) determined for the measurement series corresponding to that direction each *a priori* value ($Q^x(\nu, p)$) for each direction being proportional to that length ($L(\nu, p)$) of a corresponding beam path which extends through the body section in that region which is outside the scanning zone and in said direction, said length corresponding to the distance between the two points of intersection (x_1, y_1; x_2, y_2) of said beam path with the boundary of the body section, said boundary being determined as the envelope of all beam paths which are tangential to the boundary of the body section inside the scanning zone, or as an extension of said envelope which is determined by interpolation, the reconstruction of the absorption distribution ($\mu(x,y)$) inside the scanning zone being computed from the measurement values ($Q(\nu, p)$) and the *a priori* values ($Q^x(\nu,p)$).

2. A method as claimed in Claim 1, characterized in that for the determination of the measurement beam paths which are tangential to the boundary of the body section, those measurement values are determined which, when viewed from the centre of the scanning zone, first produce approximately the value zero, whilst all parallel beam paths which are situated further outwards from said centre also produce the value zero, the identities of the position (p_3, p_4) or the respective distances p of the measurement beam paths associated with these values, relative to the centre of the scanning zone, being stored.

3. A method as claimed in Claim 1, characterized in that when a measurement value which departs from zero is determined for a measurement direction (ν) at the outer edge of the scanning zone, the radius (R_0) of a positioning zone larger than the scanning zone and which encircles the body section, is set as a position (p_3 or p_4) of the beam path tangential to the boundary of the body section.

4. A method as claimed in Claim 1, characterized in that the envelope is formed as the locus of the vector terminii of a progressive series of central vectors ($r(\varphi)$)) each of which connects the centre of the scanning zone to the respective points of intersection of a radial line extending along the direction of said central vector with that beam path tangential to the boundary of the body section which is situated at the shortest distance along said radial line from the centre of the scanning zone.

5. A method as claimed in Claim 4, characterized in that the central vectors are formed for a finite number of angular positions (φ) which are uniformly distributed over one complete rotation.

6. A method as claimed in the Claims 1 to 4, characterized in that those central vectors ($r(\varphi)$) whose lengths are equal to or greater than the radius (R) of the scanning zone, are replaced by corrected central vectors ($r^x(\varphi)$) which are determined by interpolation from the nearest adjacent central vectors ($r(\varphi_1)$ ... $r(\varphi_2)$) whose lengths are shorter than the radius (R) of the scanning system.

7. A method as claimed in Claim 1, characterized in that in each of the measurement directions (ν) for which K (ν) is not zero, further beam paths are defined which are situated outside the scanning zone but inside a positioning zone which encircles said scanning zone, and corresponding pairs of central vectors ($r(\varphi')$, $r(\varphi'')$) are determined whose vector terminii are situated approximately on these defined further beam paths, the distance between the two vector terminii being used as a measure for the *a priori* value ($Q^x)\nu$, p)) of those beams to be complemented.

8. A method as claimed in Claim 7, characterized in that in each measurement direction (ν) the integral is formed over the distances along all those beam paths which are situated outside the scanning zone but inside the positioning zone, a proportionally factor ($C(\nu)$) being formed from the ratio of the difference ($K(\nu)$) to this integral, said proportionally factor forming the *a priori* value (Q^x) after multiplication by the distance ($L(\nu, p)$) between the two vector terminii ($r(\varphi')$, $r(\varphi'')$.

9. A method of determining the spatial distribution of absorption of radiation in a planar section of a body substantially as herein described with reference to the accompanying drawings.

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